

TRANSMITTAL LETTER TO THE UNITED STATES
DESIGNATED/ELECTED OFFICE (DO/EO/US)
CONCERNING A FILING UNDER 35 U.S.C. 371

112740-353

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR

10/031733

INTERNATIONAL APPLICATION NO.

PCT/DE00/02434

INTERNATIONAL FILING DATE

19 July 2000

PRIORITY DATE CLAIMED

19 July 1999

TITLE OF INVENTION

METHOD FOR DETERMINING THE AMPLITUDE AND PHASE ANGLE OF A MEASURING SIGNAL
CORRESPONDING TO A CURRENT OR VOLTAGE OF AN ELECTRICAL POWER SUPPLY NETWORK

APPLICANT(S) FOR DO/EO/US

Andreas Jurisch et al.

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (24) indicated below.
4. ☒ The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
 - a. ☒ is attached hereto (required only if not communicated by the International Bureau).
 - b. ☐ has been communicated by the International Bureau.
 - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☒ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
 - a. ☒ is attached hereto.
 - b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
 - a. ☐ are attached hereto (required only if not communicated by the International Bureau).
 - b. ☐ have been communicated by the International Bureau.
 - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
 - d. ☒ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
10. ☐ An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).
11. ☒ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☒ A copy of the International Search Report (PCT/ISA/210).

Items 13 to 20 below concern document(s) or information included:

13. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.
16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
17. ☒ A substitute specification.
18. ☐ A change of power of attorney and/or address letter.
19. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
20. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
21. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
22. ☒ Certificate of Mailing by Express Mail
23. ☐ Other items or information:

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR 1.101) 10/031733		INTERNATIONAL APPLICATION NO. PCT/DE00/02434		ATTORNEY'S DOCKET NUMBER 112740-353	
24. The following fees are submitted: BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) : <input type="checkbox"/> Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO \$1040.00 <input checked="" type="checkbox"/> International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO \$890.00 <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO \$740.00 <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) \$710.00 <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) \$100.00				CALCULATIONS PTO USE ONLY	
ENTER APPROPRIATE BASIC FEE AMOUNT =				\$890.00	
Surcharge of \$130.00 for furnishing the oath or declaration later than months from the earliest claimed priority date (37 CFR 1.492 (e)). <input type="checkbox"/> 20 <input type="checkbox"/> 30				\$0.00	
CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	5 - 20 =	0	x \$18.00	\$0.00	
Independent claims	1 - 3 =	0	x \$84.00	\$0.00	
Multiple Dependent Claims (check if applicable) <input type="checkbox"/>				\$0.00	
TOTAL OF ABOVE CALCULATIONS =				\$890.00	
Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2.				\$0.00	
SUBTOTAL =				\$890.00	
Processing fee of \$130.00 for furnishing the English translation later than months from the earliest claimed priority date (37 CFR 1.492 (f)). <input type="checkbox"/> 20 <input type="checkbox"/> 30				\$0.00	
TOTAL NATIONAL FEE =				\$890.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) (check if applicable). <input type="checkbox"/>				\$0.00	
TOTAL FEES ENCLOSED =				\$890.00	
				Amount to be refunded	\$
				charged	\$
a. <input checked="" type="checkbox"/> A check in the amount of \$890.00 to cover the above fees is enclosed. b. <input type="checkbox"/> Please charge my Deposit Account No. _____ in the amount of _____ to cover the above fees. A duplicate copy of this sheet is enclosed. c. <input checked="" type="checkbox"/> The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 02-1818 . A duplicate copy of this sheet is enclosed. d. <input type="checkbox"/> Fees are to be charged to a credit card. WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.					
NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.					
SEND ALL CORRESPONDENCE TO:					
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> William E. Vaughan (Reg. No. 39,056) Bell, Boyd & Lloyd LLC P.O. Box 1135 Chicago, Illinois 60690-1135 </div> <div style="width: 50%;"> <div style="text-align: center; margin-bottom: 10px;"> SIGNATURE </div> <div> William E. Vaughan NAME 39,056 REGISTRATION NUMBER January 22, 2002 DATE </div> </div> </div>					

BOX PCT

IN THE UNITED STATES ELECTED/DESIGNATED OFFICE
OF THE UNITED STATES PATENT AND TRADEMARK OFFICE
UNDER THE PATENT COOPERATION TREATY-CHAPTER II

PRELIMINARY AMENDMENT

APPLICANTS: Andreas Jurisch et al. DOCKET NO.: 112740-353
SERIAL NO: GROUP ART UNIT:
FILED: EXAMINER:
INTERNATIONAL APPLICATION NO:: PCT/DE00/02434
INTERNATIONAL FILING DATE 19 July 2000
INVENTION: METHOD FOR DETERMINING THE AMPLITUDE AND
PHASE ANGLE OF A MEASURING SIGNAL
CORRESPONDING TO A CURRENT OR VOLTAGE OF
AN ELECTRICAL POWER SUPPLY NETWORK

Assistant Commissioner for Patents
Washington, DC 20231

PRELIMINARY AMENDMENT

Sir:

Please amend the above-identified International Application before entry into the
National stage before the U.S. Patent and Trademark Office under 35 U.S.C. §371 as follows:

In the Specification:

Please replace the Specification of the present application, including the Abstract,
with the following Substitute Specification:

SPECIFICATION

TITLE OF THE INVENTION

**METHOD FOR DETERMINING THE AMPLITUDE AND PHASE ANGLE OF A
MEASURING SIGNAL CORRESPONDING TO A CURRENT OR VOLTAGE OF AN
ELECTRICAL POWER SUPPLY NETWORK**

BACKGROUND OF THE INVENTION

The present invention relates to a method for determining the amplitude and phase
angle of a measuring signal corresponding to a current or a voltage on an electrical power
supply network by using sampled values of the measuring signal, a model of the measuring

signal containing at least a sinusoidal component being used to calculate the model amplitude and phase parameters of the measuring signal with the sampled values by applying a recursive least-squares estimation method.

A method of this type is described in an article by M.S. Sachdev and M. Nagpal "A recursive least squares error algorithm for power system relaying and measurement applications", IEEE Trans. on Power Delivery, Vol. 6, No. 3, July 1991. In the case of this known method, sampled values are formed from a measuring signal corresponding to a current or voltage of an electrical power supply network and, via a linear least-squares estimation method, by using a sinusoidal signal model that models the measuring signal, are used to form a complex vector which specifies the amplitude and phase angle of the measuring signal. In this case, in a first step the real and imaginary part of the vector are in each case determined on their own. Then, in a second step, via a coordinate transformation, the polar coordinate representation of the complex vector, that is to say the magnitude and phase of the vector, can be determined from the real and imaginary part of the vector.

In the case of the known method, it is assumed that the frequency of the measuring signal is known. If this is not so, or if the frequency changes, then a separate method is needed in order to determine the frequency of the measuring signal. Methods are known, for example, which measure the distance of the zero transitions of the measuring signal and, on the basis of measuring this period, determine the frequency of the measuring signal; see, for example, E. Schröder (Editor): "Lexikon Meß- und Automatisierungstechnik" [Measurement and Automation Encyclopedia], VDI-Verlag, 1992, p. 204. Also known is a method for frequency measurement in which the measured signal to be examined is, in each case, filtered in parallel by a high-pass filter and an all-pass filter (German patent DE 42 11 946). The frequency of the measuring signal can be determined via the ratio between the amplitudes of the output signals from these two filters.

The present invention is directed toward specifying a method with which all the significant variables of the measuring signal can be determined simultaneously and quickly.

SUMMARY OF THE INVENTION

In the case of a method of the type indicated at the beginning, this object is achieved, according to the present invention, in that use is made of a model of the measuring signal containing the sinusoidal component in accordance with the relationship $y = A \cdot \sin(2\pi ft + \varphi)$, y designating an instantaneous value of the model of the measuring signal, A the amplitude, f

the frequency, φ the phase angle and t the time. By using this model of the measuring signal and by using the sampled values, via a recursive nonlinear least-squares estimation method, the model frequency parameter of the measuring signal is also determined by the estimation together with the model amplitude parameter and the model phase angle parameter.

Although it is known, from the book by H.J. Hermann, "Digitale Schutztechnik" [Digital Protection Engineering], 1997, p.p. 110-111, to use a recursive, nonlinear least-squares estimation method in protection engineering, the book does not contain any reference to the fact that by using such an estimation method, sampled values of a measuring signal can be used to determine the amplitude, phase angle and frequency of the measuring signal in a single measured-value processing process.

A significant advantage of the method according to the present invention is, however, precisely that the sampled values of the measuring signal are used to determine the frequency, as well as the amplitude and phase angle, in a measured-value processing process. Therefore, the amplitude, phase angle and frequency of the measuring signal are associated with the same point in time.

Furthermore, the patent DE 42 05 300 C1 discloses a method with which the phase angle and the amplitude of a periodic signal can be determined via a phase-locked control loop (PLL (Phase-Locked Loop)).

The use of the model for the measuring signal $y = A \cdot \sin(2\pi ft + \varphi)$ leads to good results if the measuring signal has a purely sinusoidal waveform. If there is a DC component present in the measuring signal, a model of the measuring signal in accordance with the relationship $y = A \cdot \sin(2\pi ft + \varphi) + d$ is advantageously used, the summand d modeling the DC component of the measuring signal.

If the measuring signal is a signal whose frequency changes over time, in the case of such measuring signals without a DC component, a model of the measuring signal in accordance with the relationship

$$y = A \cdot \sin \left(2\pi \sum_{i=0}^n (f^{(i)} t^i) t + \varphi \right)$$

advantageously can be used, and in the case of measuring signals with a DC component, a model of the measuring signal in accordance with the relationship

$$y = A \cdot \sin\left(2\pi \sum_{i=0}^n (f^{(i)} t^i) + \varphi\right) + d$$

advantageously can be used, $f^{(i)}$ designating the i th time derivative of the frequency and modeling a change in the frequency over time, and various orders of the time derivative of the frequency being taken into account by selecting the variable n . In these models, in an

5 extension of the model specified above, $y = A \cdot \sin(2\pi f t + \varphi)$, the frequency f is replaced by

the expression $\sum_{i=0}^n (f^{(i)} t^i)$; if only a 0th order derivative is taken into account, the integral expression becomes $f^{(0)}$ or f . These expanded models make it possible to determine frequency changes $f^{(i)}$ over time, in addition to the variables amplitude A , phase angle φ and frequency f .

In a further advantageous embodiment of the method according to the present invention, the values of the amplitude A , the phase angle φ and the frequency f determined by the estimation method are output as results only when the estimation error is less than a smallest permitted estimation error. This has the advantage that, in particular, the values estimated at the start of the method and afflicted by large estimation errors are not output, and therefore the large estimation errors cannot have any negative consequences for a user of the method.

Additional features and advantages of the present invention are described in, and will be apparent from, the following Detailed Description of the Invention and the Figures.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 shows, by using a block diagram, the progress of an exemplary embodiment of the method according to the present invention.

Figure 2 shows waveforms of a measuring signal, of an estimated signal y_s determined for the measuring signal by using a model $y = A \cdot \sin(2\pi f t + \varphi)$ and of the resulting error F .

Figure 3 shows results of the method according to the present invention in the case of a purely sinusoidal measuring signal when use is made of an appropriate model of the measuring signal, separated in accordance with the time-based waveforms of amplitude, phase angle and frequency.

Figure 4 shows results of the method according to the present invention in the case of a measuring signal subject to an offset, that is to say containing a DC component, separated in accordance with the time-based waveforms of amplitude, phase angle and frequency, when use is made of a model of the measuring signal that does not model any DC component.

Figure 5 shows results of the method according to the present invention in the case of a measuring signal subject to an offset, that is to say containing a DC component, separated in accordance with the time-based waveforms of amplitude, phase angle, frequency and DC component, when use is made of a model of the measuring signal that models a DC component.

DETAILED DESCRIPTION OF THE INVENTION

According to Figure 1, after being sampled in a sample-and-hold circuit 1 and after analog-digital conversion in an analog-digital converter 2, sampled values y_m of a measuring signal u_m are present on an input 3 of a data processing system 4. The data processing system 4 contains a unit 5 for carrying out a recursive nonlinear least-squares estimation method.

At the beginning of the recursive estimation method, starting values SW for the variables amplitude A, frequency f and phase angle φ are input into the unit 5 and are present on the output 6 of the unit 5 as estimation output values $\underline{\Theta}_{(0)}$. The estimation output values $\underline{\Theta}_{(0)}$ are led to a block 7, which contains a model of the measuring signal.

In the block 7, the estimation output values $\underline{\Theta}_{(0)}$ are used, taking into account the model of the measuring signal, to determine a starting signal value y_{s0} , which is output at the output of the block 7 and led to an input 8 of the unit 5.

The unit 5 uses a (first) sampled value y_m of the measuring signal u_m and the starting signal value y_{s0} to determine an estimation error F_{estim} in accordance with the relationship (3) recited below. This estimation error will lie above a permitted smallest estimation error. Therefore, in the unit 5 and starting from the estimation output values $\underline{\Theta}_{(0)}$, in accordance with the rules for recursive nonlinear least-square estimations, new estimated values $\underline{\Theta}_{(1)}$ are formed in accordance with the relationship (1) below, are output at the output 6 of the unit 5 and led to block 7.

In block 7, the new estimated values $\underline{\Theta}_{(1)}$ are used to determine an estimated signal value y_{s1} , which is output at the output of block 7 and is led to the input 8 of the unit 5. The unit 5 uses the (first two) sampled values y_m and the starting signal value y_{s0} and the estimated signal value y_{s1} again to form an estimation error F_{estim} in accordance with the relationship (3) recited below. This estimation error will generally also lie above the smallest

permitted estimation error. Therefore, in the unit 5 and starting from the estimated values $\underline{\Theta}_{(1)}$ on the preceding estimation, new estimated values $\underline{\Theta}_{(2)}$ are again determined in accordance with the relationship (1). These steps are repeated until the estimation error F_{estim} lies below a smallest permitted estimation error.

In order to determine whether the estimation error F_{estim} lies below a smallest permitted estimation error, use is made of a block 9. Via an input 10, block 9 obtains from the unit 5 the sampled values y_m of the measuring signal u_m , the starting signal value y_{s0} and the estimated signal values y_{s1} to y_{sk} , which are buffered in the unit 5. When the estimation error F_{estim} lies below a smallest permitted estimation error, then a switching signal, which switches a switch 12 on, is output at an output 11 of the block 9. The switch 12 then forwards the estimated values $\underline{\Theta}_{(k)}$ present at the output 6 of the unit 5 to an output 13 of the data processing system 4. The estimated values $\underline{\Theta}_{(k)}$ are then output as the resulting values from the estimation method and constitute the values for amplitude, frequency and phase angle of the measuring signal, estimated with sufficient accuracy. After that, the estimation method continues to run as described above and permits continuous determination of the estimated values $\underline{\Theta}_{(k)}$.

The unit 5 determines the estimated values $\underline{\Theta}_{(k)}$ in accordance with the following relationship (1).

$$\underline{\Theta}_{(k)} = \underline{\Theta}_{(k-1)} + \underline{P}_{(k)} \underline{\gamma}_{(k)} \left(y_{(k)} - h(\underline{\varphi}_{(k)}, \underline{\Theta}_{(k-1)}) \right) \quad (1)$$

In relationship (1), $\underline{\Theta}_{(k)}$ represents a vector which contains the estimated values of the variables to be determined, that is to say, here, the amplitude A, frequency f and phase angle φ , after k estimation steps; $\underline{\Theta}_{(k-1)}$ designates a vector which results in the case of the estimation after k-1 estimation steps. The matrix $\underline{P}_{(k)}$ is a symmetrical precision matrix, as it is known, whose determination is presented further below using the relationship (2). The

function $h(\underline{\varphi}_{(k)}, \underline{\Theta}_{(k-1)})$ contains the model of the measuring signal. The vector $\underline{\gamma}_{(k)}$ contains the partial derivatives of the model $h(\underline{\varphi}_{(k)}, \underline{\Theta}_{(k-1)})$ of the measuring signal with

respect to the parameters of the model of the measuring signal; that is to say, the derivatives with respect to amplitude, phase angle and frequency. The variable $y_{(k)}$ is the k th sampled value of the measuring signal.

In order to determine the precision matrix $\underline{P}_{(k)}$, use is made of a relationship (2).

$$\underline{P}_{(k)} = \frac{1}{\lambda} \left(\underline{P}_{(k-1)} - \frac{\underline{P}_{(k-1)} \cdot \underline{y}_{(k)}}{\lambda + \underline{y}_{(k)}^T \underline{P}_{(k-1)} \underline{y}_{(k)}} \cdot \underline{y}_{(k)}^T \underline{P}_{(k-1)} \right) \quad (2)$$

The factor λ determines the exponential weighting of preceding sampled values of the measuring signal. At the beginning of the method, a starting value is used for the precision matrix $\underline{P}_{(k)}$.

The estimation error F_{estim} after the k th estimation is determined via the relationship

$$F_{\text{scntsz}} = \frac{1}{N} \sum_{i=k-N+1}^k (y_{mi} - y_{si})^2 \quad (3)$$

Here, N is the number to be taken into account of the sampled values y_m of the measuring signal u_m and of the estimated signal values y_s , y_{mi} is the i th sampled value of the measuring signal u_m and y_{si} is the i th estimated signal value.

The estimation error F_{estim} is determined by N sampled values y_m of the measuring signal u_m and N estimated signal values y_s being evaluated. An appropriate magnitude for N is the quotient of the (sampling frequency of the sample-and-hold circuit 1) / (estimated frequency), but N also can be selected to be larger. During the first estimation pass, the value used for N is the quotient of (sampling frequency of the sample-and-hold circuit 1) / (starting value SW of the frequency). When, at the beginning of the estimation method, N sampled values y_m of the measuring signal u_m , or N estimated signal values y_{si} are not yet present, then only the present values are used to determine the estimation error F_{estim} .

Further details relating to carrying out recursive nonlinear least-squares estimation methods are described in the documents J. Wede; D. Werner: "Echtzeitprozeßmodelle auf der Basis von Parameterschätzverfahren" [Real-time process models based on parameter estimation methods], automation engineering series, Vol. 214, VEB Verlag Technik, Berlin, 1985, p.p. 30-34, p.p. 44-50, 56, 57, and Hans-Joachim Herrmann: "Digitale Schutztechnik: Grundlagen, Software, Ausführungsbeispiele" [Digital Protection Engineering: Principles, Software, Design Examples], VDE Verlag 1997, p.p. 104-113, and A. Jurisch: "Digitale

Impedanzmeßverfahren auf der Basis von Identifikationsmethoden" [Digital Impedance Measuring Methods Based on Identification Methods], Dissertation, Technische Hochschule Zittau, 1990, Annex 4.6.3.

Figure 2 shows the time-based waveform of a sinusoidal measuring signal u_m , whose amplitude, frequency and phase angle are to be determined by using the estimation method according to Figure 1. Also shown over time, as the curve y_s , are the estimated signal values $y_{s1} \dots y_{sk}$ which are output at the output of block 7. Also shown is the waveform of the values of the error F which results from the difference between the measuring signal u_m and the estimated signal values $y_{s1} \dots y_{sk}$, over time t . The waveforms shown result from an estimation method which is carried out by using the model $y = A \cdot \sin(2\pi ft + \varphi)$ for the measuring signal. It can be seen that the waveform of the curve y_s is the same as the waveform of the measuring signal u_m after about 20 ms; the error F then assumes very small values. The estimation method, therefore, permits the correct determination of the amplitude, the frequency and the phase angle of the measuring angle after about one period of the measuring signal u_m .

In Figure 3, taking into account the waveforms shown in Figure 2, the estimated values $\Theta_{(1)} \dots \Theta_{(k)}$ linked with the estimated signal values $y_{s1} \dots y_{sk}$ are plotted against the time t , separated in accordance with the variables A , ω and $2\pi f$ and φ that determine them. In an upper graph, Figure 3 shows the waveform of the amplitude A determined by the estimation method according to Figure 1, in a central graph the waveform of the variable $\omega = 2\pi f$ that is proportional to the frequency f , and in a lower graph the waveform of the phase angle φ , in each case plotted against time. According to Figure 2, the result that the time-based waveforms have reached a steady state at their final value after about 20 ms with the smallest permitted estimation error, and indicate the result of the estimation method.

Figure 4 shows, in a manner of representation which is the same as Figure 3, the time-based waveforms of amplitude A , frequency f and phase angle φ determined in a further estimation by using the model of the measuring signal $y = A \cdot \sin(2\pi ft + \varphi)$ if use is made of sampled values of a measuring signal which contains a DC component. The waveforms of frequency and phase angle also contain large time-based fluctuations for times greater than 20 ms. These fluctuations point to an erroneous estimation and are a reference to the fact that the selected model is not beneficial for a measuring signal containing a DC component.

Figure 5 shows the time-based waveforms of amplitude A, frequency f, phase angle φ and DC component d determined in an estimation using the model $y = A \cdot \sin(2\pi ft + \varphi) + d$ for the measuring signal, if use is made of sampled values of a measuring signal which contains a DC component. By using the model just mentioned of the measuring signal, fluctuations in the time-based waveforms of frequency and phase angle are avoided; consequently, an estimation which is better with regard to the estimation error is carried out.

Although the present invention has been described with reference to specific embodiment, those of skill in the art will recognize that changes may be made thereto without departing from the spirit and scope of the invention as set forth in the hereafter appended claims.

ABSTRACT OF THE DISCLOSURE

A method for determining the amplitude and phase angle of a measuring signal corresponding to a current or a voltage on an electrical power supply network by using sampled values of the measuring signal, a model of the measuring signal containing at least a sinusoidal component being used to calculate the amplitude and phase of the measuring signal with the sampled values by applying a recursive least-squares estimation method.

In order to be able to determine the frequency of the measuring signal together with the amplitude and the phase angle, use is made of a model of the measuring signal in accordance with the relationship $y = A \cdot \sin(2\pi ft + \varphi)$, and by using this model and the sampled values (y_m), the determination of the frequency of the measuring signal (u_m) as well is carried out via a recursive nonlinear least-squares estimation method. By expanding the signal model, measuring signals with a DC component and with frequencies that change over time also can be investigated.

In the claims:

On page 12, cancel line 1 and substitute the following left-hand justified heading therefore:

CLAIMS

Please cancel claims 1-5, without prejudice, and substitute the following claims therefore.

6. A method for determining an amplitude and phase angle of a measuring signal corresponding to a current or a voltage on an electrical power supply network by using sampled values of the measuring signal, the method comprising the steps of:

using a model of the measuring signal containing a sinusoidal component in accordance with the relationship $y = A \cdot \sin(2\pi ft + \varphi)$, y designating an instantaneous value of the model of the measuring signal, A designating the amplitude, f designating the frequency, φ designating the phase angle and t the time; and

using both the model of the measuring signal and the sampled values, via a recursive nonlinear least-squares estimation method, to determine the model frequency parameter of the measuring signal by the estimation together with the model amplitude parameter and the model phase angle parameter.

7. A method for determining an amplitude and phase angle of a measuring signal as claimed in claim 6, wherein use is made of a model for the measuring signal in accordance with the relationship $y = A \cdot \sin(2\pi ft + \varphi) + d$, d modeling a DC component of the measuring signal.

8. A method for determining an amplitude and phase angle of a measuring signal as claimed in claim 6, wherein use is made of a model for the measuring signal in accordance

with the relationship
$$y = A \cdot \sin\left(2\pi \sum_{i=0}^n (f^{(i)} t^i) + \varphi\right),$$
 $f^{(i)}$ designating the i th order time derivative of the frequency and modeling a change in the frequency over time, and various orders of the time derivative of the frequency being taken into account by selecting the variable n .

9. A method for determining an amplitude and phase angle of a measuring signal as claimed in claim 7, wherein use is made of a model of the measuring signal in accordance

with the relationship
$$y = A \cdot \sin\left(2\pi \sum_{i=0}^n (f^{(i)} t^i) + \varphi\right) + d,$$
 $f^{(i)}$ designating the i th time derivative of the frequency and modeling a change in the frequency over time, and various orders of the time derivative of the frequency being taken into account by selecting the variable n .

10. A method for determining an amplitude and phase angle of a measuring signal as claimed in claim 6, wherein the values of the amplitude, the phase angle and the frequency determined by the estimation method are output as resulting values only when an estimation error is less than a smallest permitted estimation error.

REMARKS

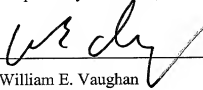
The present amendment makes editorial changes and corrects typographical errors in the specification, which includes the Abstract, in order to conform the specification to the requirements of United States Patent Practice. No new matter is added thereby.

Attached hereto is a marked-up version of the changes made to the specification and claims by the current amendment. The attached page is captioned "**Versions with Markings to Show Changes Made.**"

In addition, the present amendment cancels original claims 1-5 in favor of new claims 6-10. Claims 6-10 have been presented solely because the revisions by crossing out underlining which would have been necessary in claims 1-5 in order to present those claims in accordance with preferred United States Patent Practice would have been too extensive, and thus would have been too burdensome. The present amendment is intended for clarification purposes only and not for substantial reasons related to patentability pursuant to 35 U.S.C. §§101, 102, 103 or 112. Indeed, the cancellation of claims 1-5 does not constitute an intent on the part of the Applicants to surrender any of the subject matter of claims 1-5.

Early consideration on the merits is respectfully requested.

Respectfully submitted,



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(Reg. No. 39,056)

VERSIONS WITH MARKINGS TO SHOW CHANGES MADE

SPECIFICATION

TITLE OF THE INVENTION

5 METHOD FOR DETERMINING THE AMPLITUDE AND PHASE ANGLE OF A
 MEASURING SIGNAL CORRESPONDING TO A CURRENT OR VOLTAGE OF AN
 ELECTRICAL POWER SUPPLY NETWORK

BACKGROUND OF THE INVENTION

Description

10 Method for Determining the Amplitude and Phase Angel of a Measuring Signal
 Corresponding to a Current or Voltage of an Electrical Power Supply Network

15 The present invention relates to a method for determining the amplitude and phase
 angle of a measuring signal corresponding to a current or a voltage on an electrical power
 supply network by using sampled values of the measuring signal, a model of the measuring
 signal containing at least a sinusoidal component being used to calculate the model amplitude
 and phase parameters of the measuring signal with the sampled values by applying a recursive
 least-squares estimation method.

20 A method of this type is described in an article by M.S. Sachdev and M. Nagpal "A
 recursive least squares error algorithm for power system relaying and measurement
 applications", IEEE Trans. on Power Delivery, Vol. 6, No. 3, July 1991. In the case of this
 known method, sampled values are formed from a measuring signal corresponding to a
 current or voltage of an electrical power supply network and, ~~by means of~~ via a linear least-
 squares estimation method, by using a sinusoidal signal model that models the measuring
 signal, are used to form a complex vector, which specifies the amplitude and phase angle of
25 the measuring signal. In this case, in a first step the real and imaginary part of the vector are,
 in each case, determined on their own. Then, in a second step, ~~by means of~~ via a coordinate
 transformation, the polar coordinate representation of the complex vector, that is to say the
 magnitude and phase of the vector, can be determined from the real and imaginary part of the
 vector.

30 In the case of the known method, it is assumed that the frequency of the measuring
 signal is known. If this is not so, or if the frequency changes, then a separate method is
 needed in order to determine the frequency of the measuring signal. Methods are known

there, for example, which measure the distance of the zero transitions of the measuring signal and, on the basis of measuring this period, determine the frequency of the measuring signal; see, for example, E. Schröder (Editor): "Lexikon Meß- und Automatisierungstechnik" [Measurement and Automation Encyclopedia], VDI-Verlag, 1992, p. 204. Also known is a method for frequency measurement in which the measured signal to be examined is, in each case, filtered in parallel by a high-pass filter and an all-pass filter (German patent DE 42 11 946). The frequency of the measuring signal can be determined via the ratio between the amplitudes of the output signals from these two filters.

The present invention is ~~based on the object of directed toward~~ specifying a method with which all the significant variables of the measuring signal can be determined simultaneously and quickly.

SUMMARY OF THE INVENTION

In the case of a method of the type indicated at the beginning, this object is achieved, according to the present invention, in that use is made of a model of the measuring signal containing the sinusoidal component in accordance with the relationship $y = A \cdot \sin(2\pi ft + \varphi)$, y designating an instantaneous value of the model of the measuring signal, A the amplitude, f the frequency, φ the phase angle and t the time; ~~by~~ By using this model of the measuring signal and by using the sampled values, ~~by means of via~~ a recursive nonlinear least-squares estimation method, the model frequency parameter of the measuring signal is also determined by the estimation together with the model amplitude parameter and the model phase angle parameter.

Although it is known, from the book by H.J. Hermann, "Digitale Schutztechnik" [Digital Protection Engineering], 1997, p.p. 110-111, to use a recursive, nonlinear least-squares estimation method in protection engineering, the book does not contain any reference to the fact that by using such an estimation method, sampled values of a measuring signal can be used to determine the amplitude, phase angle and frequency of the measuring signal in a single measured-value processing process.

A significant advantage of the method according to the present invention is, however, precisely that the sampled values of the measuring signal are used to determine the frequency, as well as the amplitude and phase angle, in a measured-value processing process, ~~and therefore~~. Therefore, the amplitude, phase angle and frequency of the measuring signal are associated with the same point in time.

Furthermore, the patent DE 42 05 300 C1 discloses a method with which the phase angle and the amplitude of a periodic signal can be determined via a phase-locked control loop (PLL (Phase-Locked Loop)).

The use of the model for the measuring signal $y = A \cdot \sin(2\pi ft + \varphi)$ leads to good results if the measuring signal has a purely sinusoidal waveform. If there is a DC component present in the measuring signal, a model of the measuring signal in accordance with the relationship $y = A \cdot \sin(2\pi ft + \varphi) + d$ is advantageously used, the summand d modeling the DC component of the measuring signal.

If the measuring signal is a signal whose frequency changes over time, in the case of such measuring signals without a DC component, a model of the measuring signal in accordance with the relationship

$$y = A \cdot \sin\left(2\pi \sum_{i=0}^n (f^{(i)} t^i) t + \varphi\right)$$

can advantageously be used, and in the case of measuring signals with a DC component, a model of the measuring signal in accordance with the relationship

$$y = A \cdot \sin\left(2\pi \sum_{i=0}^n (f^{(i)} t^i) t + \varphi\right) + d$$

can advantageously be used, $f^{(i)}$ designating the i th time derivative of the frequency and modeling a change in the frequency over time, and various orders of the time derivative of the frequency being taken into account by selecting the variable n . In these models, in an extension of the model specified above, $y = A \cdot \sin(2\pi ft + \varphi)$, the frequency f is replaced by

$$\sum_{i=0}^n (f^{(i)} t^i)$$

the expression; if only a 0th order derivative is taken into account, the integral expression becomes $f^{(0)}$ or f . These expanded models make it possible to determine frequency changes $f^{(i)}$ over time, in addition to the variables amplitude A , phase angle φ and frequency f .

In a further advantageous refinement embodiment of the method according to the present invention, the values of the amplitude A , the phase angle φ and the frequency f determined by the estimation method are output as results only when the estimation error is less than a smallest permitted estimation error. This has the advantage that, in particular, the values estimated at the start of the method and afflicted by large estimation errors are not

output, and therefore the large estimation errors cannot have any negative consequences for a user of the method.

Additional features and advantages of the present invention are described in, and will be apparent from, the following Detailed Description of the Invention and the Figures.

BRIEF DESCRIPTION OF THE FIGURES

In order to explain the invention further, Figure 1 shows, by using a block diagram, the progress of an exemplary embodiment of the method according to the present invention.

Figure 2 shows waveforms of a measuring signal, of an estimated signal y_s determined for the measuring signal by using a model $y = A \cdot \sin(2\pi ft + \varphi)$ and of the resulting error F_{res} .

Figure 3 shows results of the method according to the present invention in the case of a purely sinusoidal measuring signal when use is made of an appropriate model of the measuring signal, separated in accordance with the time-based waveforms of amplitude, phase angle and frequency.

Figure 4 shows results of the method according to the present invention in the case of a measuring signal subject to an offset, that is to say containing a DC component, separated in accordance with the time-based waveforms of amplitude, phase angle and frequency, when use is made of a model of the measuring signal that does not model any DC component, and

Figure 5 shows results of the method according to the present invention in the case of a measuring signal subject to an offset, that is to say containing a DC component, separated in accordance with the time-based waveforms of amplitude, phase angle, frequency and DC component, when use is made of a model of the measuring signal that models a DC component.

DETAILED DESCRIPTION OF THE INVENTION

According to Figure 1, after being sampled in a sample-and-hold circuit 1 and after analog-digital conversion in an analog-digital converter 2, sampled values y_m of a measuring signal u_m are present on an input 3 of a data processing system 4. The data processing system 4 contains a unit 5 for carrying out a recursive nonlinear least-squares estimation method.

At the beginning of the recursive estimation method, starting values SW for the variables amplitude A, frequency f and phase angle φ are input into the unit 5 and are present on the output 6 of the unit 5 as estimation output values $\hat{\Theta}_{(0)}$. The estimation output values

$\hat{\Theta}_{(0)}$ are led to a block 7, which contains a model of the measuring signal.

In the block 7, the estimation output values $\underline{\Theta}_{(0)}$ are used, taking into account the model of the measuring signal, to determine a starting signal value y_{s0} , which is output at the output of the block 7 and led to an input 8 of the unit 5.

The unit 5 uses a (first) sampled value y_m of the measuring signal u_m and the starting signal value y_{s0} to determine an estimation error F_{estim} in accordance with the relationship (3) recited below. This estimation error will lie above a permitted smallest estimation error.

Therefore, in the unit 5 and starting from the estimation output values $\underline{\Theta}_{(0)}$, in accordance with the rules for recursive nonlinear least-square estimations, new estimated values $\underline{\Theta}_{(1)}$ are formed in accordance with the relationship (1) below, are output at the output 6 of the unit 5 and led to block 7.

In block 7, the new estimated values $\underline{\Theta}_{(1)}$ are used to determine an estimated signal value y_{s1} , which is output at the output of block 7 and is led to the input 8 of the unit 5. The unit 5 uses the (first two) sampled values y_m and the starting signal value y_{s0} and the estimated signal value y_{s1} again to form an estimation error F_{estim} in accordance with the relationship (3) recited below. This estimation error will generally also lie above the smallest permitted estimation error. Therefore, in the unit 5 and starting from the estimated values $\underline{\Theta}_{(1)}$ on the preceding estimation, new estimated values $\underline{\Theta}_{(2)}$ are again determined in accordance with the relationship (1). These steps are repeated until the estimation error F_{estim} lies below a smallest permitted estimation error.

In order to determine whether the estimation error F_{estim} lies below a smallest permitted estimation error, use is made of a block 9. Via an input 10, block 9 obtains from the unit 5 the sampled values y_m of the measuring signal u_m , the starting signal value y_{s0} and the estimated signal values y_{s1} to y_{sk} , which are buffered in the unit 5. When the estimation error F_{estim} lies below a smallest permitted estimation error, then a switching signal, which switches a switch 12 on, is output at an output 11 of the block 9. The switch 12 then forwards the estimated values $\underline{\Theta}_{(k)}$ present at the output 6 of the unit 5 to an output 13 of the data processing system 4. The estimated values $\underline{\Theta}_{(k)}$ are then output as the resulting values from the estimation method and constitute the values for amplitude, frequency and phase angle of the measuring signal, estimated with sufficient accuracy. After that, the estimation

method continues to run as described above and permits continuous determination of the estimated values $\underline{\Theta}_{(k)}$.

The unit 5 determines the estimated values $\underline{\Theta}_{(k)}$ in accordance with the following relationship (1).

$$\underline{\Theta}_{(k)} = \underline{\Theta}_{(k-1)} + \underline{P}_{(k)} \underline{Z}_{(k)} \left(y_{(k)} - h(\underline{\varphi}_{(k)}, \underline{\Theta}_{(k-1)}) \right) \quad (1)$$

In relationship (1), $\underline{\Theta}_{(k)}$ represents a vector which contains the estimated values of the variables to be determined, that is to say, here, the amplitude A, frequency f and phase angle φ , after k estimation steps; $\underline{\Theta}_{(k-1)}$ designates a vector which results in the case of the estimation after k-1 estimation steps. The matrix $\underline{P}_{(k)}$ is a symmetrical precision matrix, as it is known, whose determination is presented further below using the relationship (2). The function $h(\underline{\varphi}_{(k)}, \underline{\Theta}_{(k-1)})$ contains the model of the measuring signal. The vector $\underline{Y}_{(k)}$ contains the partial derivatives of the model $h(\underline{\varphi}_{(k)}, \underline{\Theta}_{(k-1)})$ of the measuring signal with respect to the parameters of the model of the measuring signal; that is to say, the derivatives with respect to amplitude, phase angle and frequency. The variable $y_{(k)}$ is the kth sampled value of the measuring signal.

In order to determine the precision matrix $\underline{P}_{(k)}$, use is made of a relationship (2).

$$\underline{P}_{(k)} = \frac{1}{\lambda} \left(\underline{P}_{(k-1)} - \frac{\underline{P}_{(k-1)} \cdot \underline{Y}_{(k)}}{\lambda + \underline{Y}_{(k)}^T \underline{P}_{(k-1)} \underline{Y}_{(k)}} \cdot \underline{Y}_{(k)}^T \underline{P}_{(k-1)} \right) \quad (2)$$

The factor λ determines the exponential weighting of preceding sampled values of the measuring signal. At the beginning of the method, a starting value is used for the precision matrix $\underline{P}_{(k)}$.

The estimation error F_{estim} after the kth estimation is determined by means of via the relationship

$$F_{\text{schätz}} = \frac{1}{N} \sum_{i=K-N+1}^K (y_{mi} - y_{si})^2 \quad (3)$$

Here, N is the number to be taken into account of the sampled values y_{mi} of the measuring signal u_m and of the estimated signal values y_{si} , y_{mi} is the i th sampled value of the measuring signal u_m and y_{si} is the i th estimated signal value.

The estimation error F_{estim} is determined by N sampled values y_{mi} of the measuring signal u_m and N estimated signal values y_{si} being evaluated. An appropriate magnitude for N is the quotient of the (sampling frequency of the sample-and-hold circuit 1) / (estimated frequency), but N can also can be selected to be larger. During the first estimation pass, the value used for N is the quotient of (sampling frequency of the sample-and-hold circuit 1) / (starting value SW of the frequency). When, at the beginning of the estimation method, N sampled values y_{mi} of the measuring signal u_m or N estimated signal values y_{si} are not yet present, then only the present values are used to determine the estimation error F_{estim} .

Further details relating to carrying out recursive nonlinear least-squares estimation methods are described in the documents J. Wede; D. Werner: "Echtzeitprozeßmodelle auf der Basis von Parameterschätzverfahren" [Real-time process models based on parameter estimation methods], automation engineering series, Vol. 214, VEB Verlag Technik, Berlin, 1985, p.p. 30-34, p.p. 44-50, 56, 57, and Hans-Joachim Herrmann: "Digitale Schutztechnik: Grundlagen, Software, Ausführungsbeispiele" [Digital Protection Engineering: Principles, Software, Design Examples], VDE Verlag 1997, p.p. 104-113, and A. Jurisch: "Digitale Impedanzmeßverfahren auf der Basis von Identifikationsmethoden" [Digital Impedance Measuring Methods Based on Identification Methods], Dissertation, Technische Hochschule Zittau, 1990, Annex 4.6.3.

Figure 2 shows the time-based waveform of a sinusoidal measuring signal u_m , whose amplitude, frequency and phase angle are to be determined by using the estimation method according to Figure 1. Also shown over time, as the curve y_s , are the estimated signal values $y_{s1} \dots y_{sk}$ which are output at the output of block 7. Also shown is the waveform of the values of the error F which results from the difference between the measuring signal u_m and the estimated signal values $y_{s1} \dots y_{sk}$, over time t . The waveforms shown result from an estimation method which is carried out by using the model $y = A \cdot \sin(2\pi ft + \varphi)$ for the measuring signal. It can be seen that the waveform of the curve y_s is the same as the

waveform of the measuring signal u_m after about 20 ms; the error F then assumes very small values. The estimation method, therefore, permits the correct determination of the amplitude, the frequency and the phase angle of the measuring angle after about one period of the measuring signal u_m .

In Figure 3, taking into account the waveforms shown in Figure 2, the estimated values $\hat{\omega}_{(1)} \dots \hat{\omega}_{(k)}$ linked with the estimated signal values $y_{s1} \dots y_{sk}$ are plotted against the time t , separated in accordance with the variables A , ω and $2\pi f$ and φ that determine them. In an upper graph, Figure 3 shows the waveform of the amplitude A determined by the estimation method according to Figure 1, in a central graph the waveform of the variable $\omega = 2\pi f$ that is proportional to the frequency f , and in a lower graph the waveform of the phase angle φ , in each case plotted against time. According to Figure 2, the result that the time-based waveforms have reached a steady state at their final value after about 20 ms with the smallest permitted estimation error, and indicate the result of the estimation method.

Figure 4 shows, in a manner of representation which is the same as Figure 3, the time-based waveforms of amplitude A , frequency f and phase angle φ determined in a further estimation by using the model of the measuring signal $y = A \cdot \sin(2\pi f t + \varphi)$ if use is made of sampled values of a measuring signal which contains a DC component. The waveforms of frequency and phase angle also contain large time-based fluctuations for times greater than 20 ms. These fluctuations point to an erroneous estimation and are a reference to the fact that the selected model is not beneficial for a measuring signal containing a DC component.

Figure 5 shows the time-based waveforms of amplitude A , frequency f , phase angle φ and DC component d determined in an estimation using the model $y = A \cdot \sin(2\pi f t + \varphi) + d$ for the measuring signal, if use is made of sampled values of a measuring signal which contains a DC component. By using the model just mentioned of the measuring signal, fluctuations in the time-based waveforms of frequency and phase angle are avoided; consequently, an estimation which is better with regard to the estimation error is carried out.

Although the present invention has been described with reference to specific embodiment, those of skill in the art will recognize that changes may be made thereto without departing from the spirit and scope of the invention as set forth in the hereafter appended claims.

3/pths

GR 99 P 4121

Description

Method for determining the amplitude and phase angle of a measuring signal corresponding to a current or voltage of an electrical power supply network

The invention relates to a method for determining the amplitude and phase angle of a measuring signal corresponding to a current or a voltage on an electrical power supply network by using sampled values of the measuring signal, a model of the measuring signal containing at least a sinusoidal component being used to calculate the model amplitude and phase parameters of the measuring signal with the sampled values by applying a recursive least-squares estimation method.

A method of this type is described in an article by M.S. Sachdev and M. Nagpal "A recursive least squares error algorithm for power system relaying and measurement applications", IEEE Trans. on Power Delivery, Vol. 6, No. 3, July 1991. In the case of this known method, sampled values are formed from a measuring signal corresponding to a current or voltage of an electrical power supply network and, by means of a linear least-squares estimation method, by using a sinusoidal signal model that models the measuring signal, are used to form a complex vector, which specifies the amplitude and phase angle of the measuring signal. In this case, in a first step the real and imaginary part of the vector are in each case determined on their own. Then, in a second step, by means of a coordinate transformation, the polar coordinate representation of the complex vector, that is to say the magnitude and phase of the vector, can be determined from the real and imaginary part of the vector.

- In the case of the known method, it is assumed that the frequency of the measuring signal is known. If this is not so, or if the frequency changes, then a separate method is needed in order to determine the frequency of the measuring signal. Methods are known there, for example, which measure the distance of the zero transitions of the measuring signal and, on the basis of measuring this period, determine the frequency of the measuring signal, see, for example, E. Schröder (Editor): "Lexikon Meß- und Automatisierungstechnik" [Measurement and Automation Encyclopedia], VDI-Verlag, 1992, p.204. Also known is a method for frequency measurement in which the measured signal to be examined is in each case filtered in parallel by a high-pass filter and an all-pass filter (German patent DE 42 11 946). The frequency of the measuring signal can be determined via the ratio between the amplitudes of the output signals from these two filters.
- The invention is based on the object of specifying a method with which all the significant variables of the measuring signal can be determined simultaneously and quickly.
- In the case of a method of the type indicated at the beginning, this object is achieved, according to the invention, in that use is made of a model of the measuring signal containing the sinusoidal component in accordance with the relationship $y = A \cdot \sin(2\pi ft + \phi)$, y designating an instantaneous value of the model of the measuring signal, A the amplitude, f the frequency, ϕ the phase angle and t the time; by using this model of the measuring signal and by using the sampled values, by means of a recursive nonlinear least-squares estimation method, the model frequency parameter of the measuring signal is also determined by the estimation together with the model amplitude parameter and the model phase angle parameter.

Although it is known, from the book by H.-J. Hermann, "Digitale Schutztechnik" [Digital Protection Engineering], 1997, pp. 110-111, to use a recursive, nonlinear least-squares estimation method in protection engineering, the book does not contain any reference to the fact that by using such an estimation method, sampled values of a measuring signal can be used to determine the amplitude, phase angle and frequency of the measuring signal in a single measured-value processing process.

A significant advantage of the method according to the invention is, however, precisely that the sampled values of the measuring signal are used to determine the frequency, as well as the amplitude and phase angle, in a measured-value processing process, and therefore the amplitude, phase angle and frequency of the measuring signal are associated with the same point in time.

Furthermore, the patent DE 42 05 300 C1 discloses a method with which the phase angle and the amplitude of a periodic signal can be determined via a phase-locked control loop (PLL (Phase-Locked Loop)).

The use of the model for the measuring signal $y = A \cdot \sin(2\pi ft + \varphi)$ leads to good results if the measuring signal has a purely sinusoidal waveform. If there is a DC component present in the measuring signal, a model of the measuring signal in accordance with the relationship $y = A \cdot \sin(2\pi ft + \varphi) + d$ is advantageously used, the summand d modeling the DC component of the measuring signal.

If the measuring signal is a signal whose frequency changes over time, in the case of such measuring signals without a DC component, a model of the measuring signal in accordance with the relationship

$$y = A \cdot \sin \left(2\pi \sum_{i=0}^n (f^{(i)} t^i) + \varphi \right)$$

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can advantageously be used, and in the case of measuring signals with a DC component, a model of the measuring signal in accordance with the relationship

$$y = A \cdot \sin \left(2\pi \sum_{i=0}^n (f^{(i)} t^i) + \varphi \right) + d$$

- 10 can advantageously be used, $f^{(i)}$ designating the i th time derivative of the frequency and modeling a change in the frequency over time, and various orders of the time derivative of the frequency being taken into account by selecting the variable n . In these models,
- 15 in an extension of the model specified above, $y = A \cdot \sin(2\pi f t + \varphi)$, the frequency f is replaced by the expression $\sum_{i=0}^n (f^{(i)} t^i)$; if only a 0th order derivative is taken into account, the integral expression becomes $f^{(0)}$ or f .
- 20 These expanded models make it possible to determine frequency changes $f^{(i)}$ over time, in addition to the variables amplitude A , phase angle φ and frequency f .

- 25 In a further advantageous refinement of the method according to the invention, the values of the amplitude A , the phase angle φ and the frequency f determined by the estimation method are output as results only when the estimation error is less than a smallest permitted estimation error. This has the advantage that, in
- 30 particular, the values estimated at the start of the method and afflicted by large estimation errors are not output, and therefore the large

estimation errors cannot have any negative consequences for a user of the method.

In order to explain the invention further,

- 5 figure 1 shows, by using a block diagram, the progress of an exemplary embodiment of the method according to the invention,
- figure 2 shows waveforms of a measuring signal, of an estimated signal y_e , determined for the measuring signal
- 10 by using a model $y = A \cdot \sin(2\pi ft + \phi)$ and of the resulting error F ,
- figure 3 shows results of the method according to the invention in the case of a purely sinusoidal measuring signal when use is made of an appropriate model of the
- 15 measuring signal, separated in accordance with the time-based waveforms of amplitude, phase angle and frequency,
- figure 4 shows results of the method according to the invention in the case of a measuring signal subject to an offset, that is to say containing a DC component,
- 20 separated in accordance with the time-based waveforms of amplitude, phase angle and frequency, when use is made of a model of the measuring signal that does not model any DC component, and
- 25 figure 5 shows results of the method according to the invention in the case of a measuring signal subject to an offset, that is to say containing a DC component, separated in accordance with the time-based waveforms of amplitude, phase angle, frequency and DC component,
- 30 when use is made of a model of the measuring signal that models a DC component.

- According to figure 1, after being sampled in a sample-and-hold circuit 1 and after analog-digital conversion
- 35 in an analog-digital converter 2, sampled values y_m of a measuring signal u_m are present on an input 3 of a data processing system 4. The data processing system 4

contains a unit 5 for carrying out a recursive nonlinear least-squares estimation method.

At the beginning of the recursive estimation method,
5 starting values SW for the variables amplitude A, frequency f and phase angle ϕ are input into the unit 5 and are present on the output 6 of the unit 5 as estimation output values $\underline{\Theta}_{(0)}$. The estimation output values $\underline{\Theta}_{(0)}$ are led to a block 7, which contains a model
10 of the measuring signal.

In the block 7, the estimation output values $\underline{\Theta}_{(0)}$ are used, taking into account the model of the measuring signal, to determine a starting signal value y_{s0} , which
15 is output at the output of the block 7 and led to an input 8 of the unit 5.

The unit 5 uses a (first) sampled value y_m of the measuring signal u_m and the starting signal value y_{s0} to
20 determine an estimation error F_{estim} in accordance with the relationship (3) recited below. This estimation error will lie above a permitted smallest estimation error. Therefore, in the unit 5 and starting from the estimation output values $\underline{\Theta}_{(0)}$, in accordance with the
25 rules for recursive nonlinear least-square estimations, new estimated values $\underline{\Theta}_{(1)}$ are formed in accordance with the relationship (1) below, are output at the output 6 of the unit 5 and led to block 7.

30 In block 7, the new estimated values $\underline{\Theta}_{(1)}$ are used to determine an estimated signal value y_{s1} , which is output at the output of block 7 and is led to the input 8 of the unit 5. The unit 5 uses the (first two) sampled values y_m and the starting signal value y_{s0} and the
35 estimated signal value y_{s1} again to form an estimation

error F_{estim} in accordance with the relationship (3) recited below. This estimation error will generally also lie above the smallest permitted estimation error. Therefore, in the unit 5 and starting from the
 5 estimated values $\underline{\Theta}_{(1)}$ on the preceding estimation, new estimated values $\underline{\Theta}_{(2)}$ are again determined in accordance with the relationship (1). These steps are repeated until the estimation error F_{estim} lies below a smallest permitted estimation error.

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In order to determine whether the estimation error F_{estim} lies below a smallest permitted estimation error, use is made of a block 9. Via an input 10, block 9 obtains from the unit 5 the sampled values y_m of the measuring
 15 signal u_m , the starting signal value y_{s0} and the estimated signal values y_{s1} to y_{sk} , which are buffered in the unit 5. When the estimation error F_{estim} lies below a smallest permitted estimation error, then a switching signal, which switches a switch 12 on, is
 20 output at an output 11 of the block 9. The switch 12 then forwards the estimated values $\underline{\Theta}_{(k)}$ present at the output 6 of the unit 5 to an output 13 of the data processing system 4. The estimated values $\underline{\Theta}_{(k)}$ are then
 25 output as the resulting values from the estimation method and constitute the values for amplitude, frequency and phase angle of the measuring signal, estimated with sufficient accuracy. After that, the estimation method continues to run as described above and permits continuous determination of the estimated
 30 values $\underline{\Theta}_{(k)}$.

The unit 5 determines the estimated values $\underline{\Theta}_{(k)}$ in accordance with the following relationship (1).

$$\underline{\Theta}_{(k)} = \underline{\Theta}_{(k-1)} + \underline{P}_{(k)} \underline{\gamma}_{(k)} \left(y_{(k)} - h \left(\underline{\varphi}_{(k)}, \underline{\Theta}_{(k-1)} \right) \right) \quad (1)$$

In relationship (1), $\underline{\Theta}_{(k)}$ represents a vector which contains the estimated values of the variables to be determined, that is to say, here, the amplitude A, frequency f and phase angle ϕ , after k estimation steps; $\underline{\Theta}_{(k-1)}$ designates a vector which results in the case of the estimation after k-1 estimation steps. The matrix $\underline{P}_{(k)}$ is a symmetrical precision matrix, as it is known, whose determination is presented further below using the relationship (2). The function $h(\underline{\Theta}_{(k)}, \underline{\Theta}_{(k-1)})$ contains the model of the measuring signal. The vector $\underline{\gamma}_{(k)}$ contains the partial derivatives of the model $h(\underline{\Theta}_{(k)}, \underline{\Theta}_{(k-1)})$ of the measuring signal with respect to the parameters of the model of the measuring signal, that is to say the derivatives with respect to amplitude, phase angle and frequency. The variable $y_{(k)}$ is the kth sampled value of the measuring signal.

In order to determine the precision matrix $\underline{P}_{(k)}$, use is made of a relationship (2).

$$\underline{P}_{(k)} = \frac{1}{\lambda} \left(\underline{P}_{(k-1)} - \frac{\underline{P}_{(k-1)} \cdot \underline{\gamma}_{(k)}}{\lambda + \underline{\gamma}_{(k)}^T \underline{P}_{(k-1)} \underline{\gamma}_{(k)}} \cdot \underline{\gamma}_{(k)}^T \underline{P}_{(k-1)} \right) \quad (2)$$

The factor λ determines the exponential weighting of preceding sampled values of the measuring signal. At the beginning of the method, a starting value is used for the precision matrix $\underline{P}_{(k)}$.

The estimation error F_{estim} after the kth estimation is determined by means of the relationship

$$F_{\text{schätz}} = \frac{1}{N} \sum_{i=k-N+1}^k (y_{m_i} - y_{s_i})^2 \quad (3)$$

Here, N is the number to be taken into account of the sampled values y_m of the measuring signal u_m and of the estimated signal values y_{si} , y_{mi} is the i th sampled value of the measuring signal u_m and y_{si} is the i th estimated signal value.

The estimation error F_{estim} is determined by N sampled values y_{mi} of the measuring signal u_m and N estimated signal values y_{si} being evaluated. An appropriate magnitude for N is the quotient of the (sampling frequency of the sample-and-hold circuit 1) / (estimated frequency), but N can also be selected to be larger. During the first estimation pass, the value used for N is the quotient of (sampling frequency of the sample-and-hold circuit 1) / (starting value SW of the frequency). When, at the beginning of the estimation method, N sampled values y_{mi} of the measuring signal u_m , or N estimated signal values y_{si} are not yet present, then only the present values are used to determine the estimation error F_{estim} .

Further details relating to carrying out recursive nonlinear least-squares estimation methods are described in the documents J. Wede; D. Werner: "Echtzeitprozeßmodelle auf der Basis von Parameterschätzverfahren" [Real-time process models based on parameter estimation methods], automation engineering series, Vol. 214, VEB Verlag Technik, Berlin, 1985, p.p. 30-34, pp. 44-50, 56, 57, and Hans-Joachim Herrmann: "Digitale Schutztechnik: Grundlagen, Software, Ausführungsbeispiele" [Digital Protection Engineering: Principles, Software, Design Examples], VDE Verlag 1997, pp. 104-113, and A. Jurisch: "Digitale Impedanzmeßverfahren auf der Basis von Identifikationsmethoden" [Digital Impedance Measuring Methods Based on Identification Methods], Dissertation, Technische Hochschule Zittau, 1990, Annex 4.6.3.

- 9a -

Figure 2 shows the time-based waveform of a sinusoidal measuring signal u_m , whose amplitude, frequency and phase angle

REFORM

are to be determined by using the estimation method according to figure 1. Also shown over time, as the curve y_s , are the estimated signal values $y_{s1} \dots y_{sk}$ which are output at the output of block 7. Also shown

5 is the waveform of the values of the error F which results from the difference between the measuring signal u_m and the estimated signal values $y_{s1} \dots y_{sk}$, over time t . The waveforms shown result from an estimation method which is carried out by using the

10 model $y = A \cdot \sin(2\pi ft + \varphi)$ for the measuring signal. It can be seen that the waveform of the curve y_s is the same as the waveform of the measuring signal u_m after about 20 ms; the error F then assumes very small values. The estimation method therefore permits the

15 correct determination of the amplitude, the frequency and the phase angle of the measuring angle after about one period of the measuring signal u_m .

In figure 3, taking into account the waveforms shown in

20 figure 2, the estimated values $\Theta_{(1)} \dots \Theta_{(k)}$ linked with the estimated signal values $y_{s1} \dots y_{sk}$ are plotted against the time t , separated in accordance with the variables A , ω and $2\pi f$ and φ that determine them. In an upper graph, figure 3 shows the waveform of the

25 amplitude A determined by the estimation method according to figure 1, in a central graph the waveform of the variable $\omega = 2\pi f$ that is proportional to the frequency f , and in a lower graph the waveform of the phase angle φ , in each case plotted against time.

30 According to figure 2, the result that the time-based waveforms have reached a steady state at their final value after about 20 ms with the smallest permitted estimation error, and indicate the result of the estimation method.

35

Figure 4 shows, in a manner of representation which is the same as figure 3, the time-based waveforms

of amplitude A , frequency f and phase angle ϕ determined in a further estimation by using the model of the measuring signal $y = A \cdot \sin(2\pi ft + \phi)$ if use is made of sampled values of a measuring signal which contains a DC component. The waveforms of frequency and phase angle also contain large time-based fluctuations for times greater than 20 ms. These fluctuations point to an erroneous estimation and are a reference to the fact that the selected model is not beneficial for a measuring signal containing a DC component.

Figure 5 shows the time-based waveforms of amplitude A , frequency f , phase angle ϕ and DC component d determined in an estimation using the model $y = A \cdot \sin(2\pi ft + \phi) + d$ for the measuring signal, if use is made of sampled values of a measuring signal which contains a DC component. By using the model just mentioned of the measuring signal, fluctuations in the time-based waveforms of frequency and phase angle are avoided; consequently, an estimation which is better with regard to the estimation error is carried out.

Patent claims

1. A method for determining the amplitude and phase angle of a measuring signal corresponding to a current or a voltage on an electrical power supply network by using sampled values of the measuring signal, a model of the measuring signal containing at least a sinusoidal component being used to calculate the model amplitude and phase parameters of the measuring signal with the sampled values by applying a recursive least-squares estimation method, characterized in that
- use is made of a model of the measuring signal containing the sinusoidal component in accordance with the relationship $y = A \cdot \sin(2\pi ft + \varphi)$, y designating an instantaneous value of the model of the measuring signal, A the amplitude, f the frequency, φ the phase angle and t the time, and
 - by using this model of the measuring signal and by using the sampled values, by means of a recursive nonlinear least-squares estimation method, the model frequency parameter (f) of the measuring signal is also determined by the estimation together with the model amplitude parameter (A) and the model phase angle parameter (φ).
2. The method as claimed in claim 1, characterized in that use is made of a model for the measuring signal in accordance with the relationship $y = A \cdot \sin(2\pi ft + \varphi) + d$, d modeling the DC component of the measuring signal.
3. The method as claimed in claim 1, characterized in that use is made of a model for the measuring signal in accordance with the relationship

$$y = A \cdot \sin \left(2\pi \sum_{i=0}^n (f^{(i)} t^i) + \varphi \right),$$
 $f^{(i)}$ designating the i th order time derivative of the frequency and modeling a change in the frequency over time, and various orders of the time derivative of the frequency being taken into account by selecting the variable n .

4. The method as claimed in claim 2, characterized in that use is made of a model of the measuring signal in accordance with the relationship

$$y = A \cdot \sin \left(2\pi \sum_{i=0}^n (f^{(i)} t^i) + \varphi \right) + d,$$

$f^{(i)}$ designating the i th time derivative of the frequency and modeling a change in the frequency over time, and various orders of the time derivative of the frequency being taken into account by selecting the variable n .
5. The method as claimed in one of claims 1 to 4, characterized in that the values of the amplitude (A), the phase angle (φ) and the frequency (f) determined by the estimation method are output as resulting values only when the estimation error is less than a smallest permitted estimation error.

Abstract

Method for determining the amplitude and phase angle of a measuring signal corresponding to a current or voltage of an electrical power supply network

The invention relates to a method for determining the amplitude and phase angle of a measuring signal corresponding to a current or a voltage on an electrical power supply network by using sampled values of the measuring signal, a model of the measuring signal containing at least a sinusoidal component being used to calculate the amplitude and phase of the measuring signal with the sampled values by applying a recursive least-squares estimation method.

In order to be able to determine the frequency of the measuring signal together with the amplitude and the phase angle, use is made of a model of the measuring signal in accordance with the relationship $y = A \cdot \sin(2\pi ft + \phi)$, and by using this model and the sampled values (y_m), the determination of the frequency of the measuring signal (u_m) as well is carried out by means of a recursive nonlinear least-squares estimation method. By expanding the signal model, measuring signals with a DC component and with frequencies that change over time can also be investigated.

FIG 1

ABSTRACT OF THE DISCLOSURE

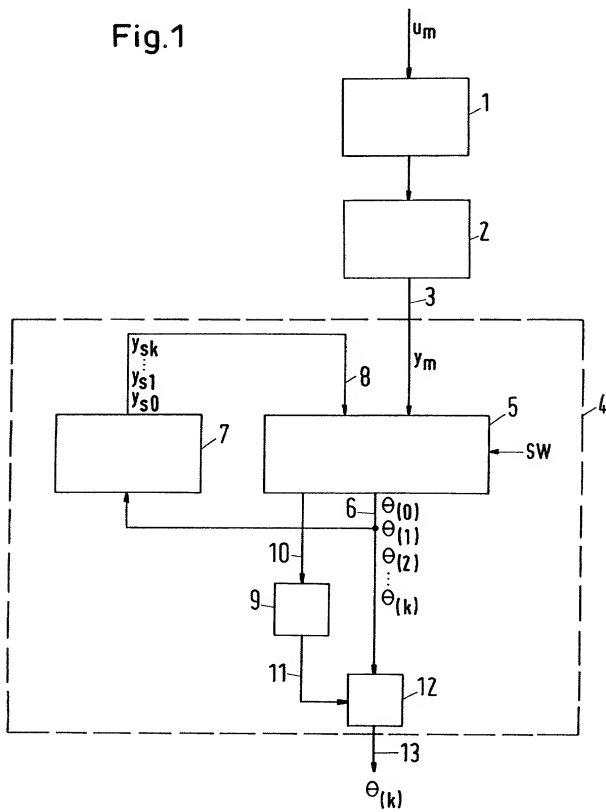
Abstract

Method for determining the amplitude and phase angle of a measuring signal corresponding to a current or voltage of an electrical power supply network

5 ~~The invention relates to a~~ A method for determining the amplitude and phase angle of a measuring signal corresponding to a current or a voltage on an electrical power supply network by using sampled values of the measuring signal, a model of the measuring signal containing at least a sinusoidal component being used to calculate the amplitude and phase of the measuring signal with the sampled values by applying a recursive least-squares estimation
10 method. In order to be able to determine the frequency of the measuring signal together with the amplitude and the phase angle, use is made of a model of the measuring signal in accordance with the relationship $y = A \cdot \sin(2\pi ft + \varphi)$, and by using this model and the sampled values (y_m), the determination of the frequency of the measuring signal (u_m) as well is carried out ~~by means of~~ via a recursive nonlinear least-squares estimation method. By
15 expanding the signal model, measuring signals with a DC component and with frequencies that change over time ~~can~~ also can be investigated.

FIG 1

Fig.1



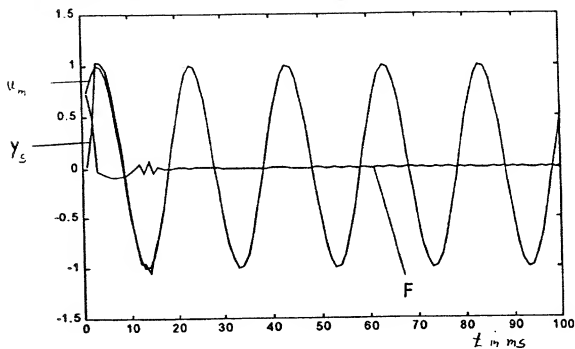


Fig. 2,

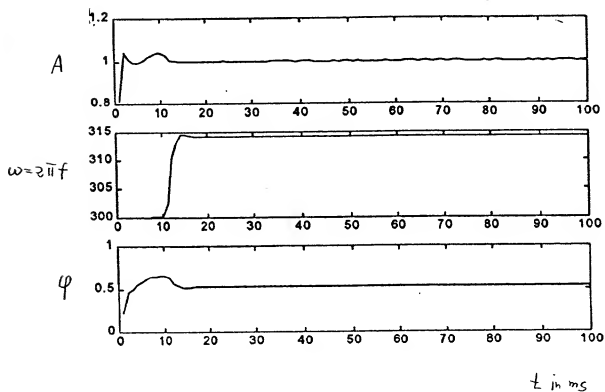
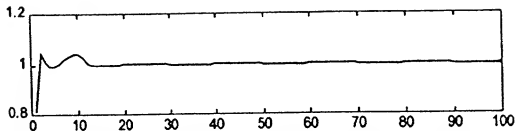


Fig. 3

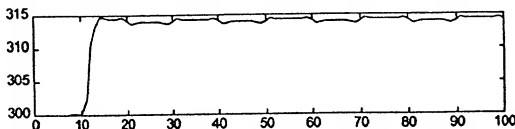
95 F 4 1 2 1

107031733

A



$\omega = 2\pi f$



ϕ

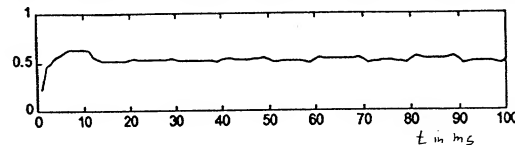
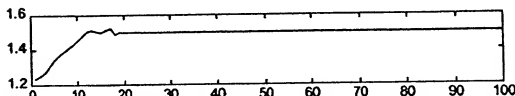
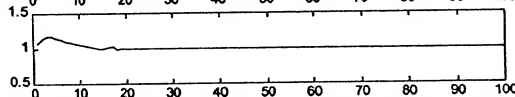


Fig. 4

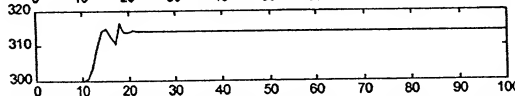
d



A



$f = 2\pi$



ϕ

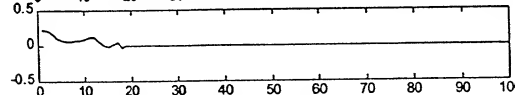


Fig. 5

t in ms

Declaration and Power of Attorney For Patent Application

Erklärung Für Patentanmeldungen Mit Vollmacht

German Language Declaration

Als nachstehend benannter Erfinder erkläre ich hiermit an Eides Statt:

As a below named inventor, I hereby declare that

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I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

Verfahren zum Ermitteln von Amplitude
und Phasenwinkel eines einem Strom
oder einer Spannung eines elektrischen
Energieversorgungsnetzes
entsprechenden Messsignals

Method for determining the amplitude
and angle of phase of a measuring
signal corresponding to the current
or voltage of an electric power
distribution system

deren Beschreibung

the specification of which

(zutreffendes ankreuzen)

(check one)

☐ hier beigelegt ist.

☐ is attached hereto.

☒ am 19.07.2000 als

☒ was filed on 19.07.2000 as

PCT internationale Anmeldung PCT/DE00/02434

PCT international application PCT/DE00/02434

PCT Anmeldungsnummer _____

PCT Application No. _____

eingereicht wurde und am _____

and was amended on _____

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(if applicable)

Ich bestätige hiermit, dass ich den Inhalt der obigen Patentanmeldung einschliesslich der Ansprüche durchgesehen und verstanden habe, die eventuell durch einen Zusatzantrag wie oben erwähnt abgeändert wurde.

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I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a).

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I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

10031733-012262

IDNR: 2590 / V: 99-1.00 / B: Val

German Language Declaration

Prior foreign applications
Priorität beansprucht

Priority Claimed

19934055.2

DE

19.07.1999

☒

☐

(Number)
(Number)

(Country)
(Land)

(Day Month Year Filed)
(Tag Monat Jahr eingereicht)

Yes
Ja

No
Nein

(Number)
(Number)

(Country)
(Land)

(Day Month Year Filed)
(Tag Monat Jahr eingereicht)

☐
Yes
Ja

☐
No
Nein

(Number)
(Number)

(Country)
(Land)

(Day Month Year Filed)
(Tag Monat Jahr eingereicht)

☐
Yes
Ja

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Ich beanspruche hiermit gemäss Absatz 35 der Zivilprozessordnung der Vereinigten Staaten, Paragraph 120, den Vorzug aller unten aufgeführten Anmeldungen und falls der Gegenstand aus jedem Anspruch dieser Anmeldung nicht in einer früheren amerikanischen Patentanmeldung laut dem ersten Paragraphen des Absatzes 35 der Zivilprozessordnung der Vereinigten Staaten, Paragraph 122 offenbart ist, erkenne ich gemäss Absatz 37, Bundesgesetzbuch, Paragraph 1.56(a) meine Pflicht zur Offenbarung von Informationen an, die zwischen dem Anmeldedatum der früheren Anmeldung und dem nationalen oder PCT internationalen Anmeldedatum dieser Anmeldung bekannt geworden sind.

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §122, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application.

PCT/DE00/02434
(Application Serial No.)
(Anmeldeseriennummer)

19.07.2000
(Filing Date D, M, Y)
(Anmeldedatum T, M, J)

(Status)
(patentiert, anhängig,
aufgegeben)

pending
(Status)
(patented, pending,
abandoned)

(Application Serial No.)
(Anmeldeseriennummer)

(Filing Date D, M, Y)
(Anmeldedatum T, M, J)

(Status)
(patentiert, anhängig,
aufgeben)

(Status)
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10031733-012202

German Language Declaration

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POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. (list name and registration number)



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Unterschrift des Erfinders <i>Dieter Kramer</i>	Datum 2 - 00	Second inventor's signature <i>Dieter Kramer</i>	Date 06.11.01
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